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Variations in the performance of maize *(Zea mayz)* yield under reclaimed wastewater irrigation in south-eastern Australia: Management of salinity, water and nutrient budgets

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Abstract

This study explores the variations of maize growth performance under reclaimed wastewater irrigation and whether the dissimilarities in growth between and within the irrigation bays depend on dysfunctional salt, water or nutrient budgets. The experiment was conducted by Melbourne Water in conjunction with the Swedish University of Agricultural Studies at Melbourne Water's Western Treatment Plant in south-eastern Australia during the growing season of 2005/2006.

Soil sampling from four irrigation bays found a generally lower electrical conductivity (EC) of the surface (0-10cm) than expected and those salt concentrations would not have had a severe impact on maize growth. However, some samples showed high salinity, still, the correlation with maize performance, measured as crop height (m), was very low (R^2 0.02-0.44). Deep profile sampling could not be done in this study, hence, the salinity with depth was not explored.

Information on current irrigation application (frequency and amounts) and water quality (salinity and nutrients) were collated from available data and processed. The current irrigation schedule was found to be too infrequent with too much water being applied at each of the irrigation events. The irrigation water salinity was rather low and would not have had a severe effect on crop growth in its own right and the nutrients applied through the irrigation water appeared to be within a, for the crop, proper range.

In conclusion, possible high salt concentrations with depth may still be a problem for maize growth and should be investigated further and the irrigation application will have to change to a more frequent schedule with less amount of water applied at each irrigation event. The nutrients will have to be measured at the irrigation bays, not in the lagoons and pumping stations as it is done today, because the nutrient chemistry in the water may change along its way to the crop in such a way that the maize nutrient requirement is not met although believed so. Furthermore, one bay showed extremely high pH, which, together with low salinity is an indication of high sodicity, a factor that was only briefly explored in this study and should be researched extensively as it could have a severe impact on maize growth. Additionally, further studies on groundwater levels and drainage are required to make sure that a healthy environment for maize growth is created.

List of figures and tables

Abbreviations

EC	Electrical Conductivity
EC_e	Electrical Conductivity of the saturation extract
dS/m	deci Siemens per metre
WTP	Western Treatment Plant
EPA	The Environmental Protection Agency
SAR	Sodium Adsorption Ratio
ESR	Exchangeable Sodium Ratio
ESP	Exchangeable Sodium Percentage
CEC	Cation Exchange Capacity
FAO	Food and Agricultural Organisation of the United Nations
DPI	Department of Primary Industries
LF	Leaching Fraction
LR	Leaching Requirement
CWM	Controlled Water Table
DM/ha	Dry matter per hectare

1. Introduction

Accelerating water demand due to increasing populations is an issue that many regions in the world are facing today. One way to meet future needs of water and mitigate pressure on fresh water sources is to recycle and treat wastewater from domestic and industrial uses (Postel 1997). In densely populated areas such as Europe and in arid areas such as the Arabic countries, irrigation of treated recycled water has been a practice for a long time already (Scott et al 2004). Irrigating crops and pastures is only one of many ways in which to use recycled water (Charles Sturt University, 1992). However, there are still many concerns regarding wastewater which must be carefully investigated from a social, economical and environmental perspective (Scott et al 2004).

At Melbourne's Western Treatment Plant (WTP) the recycling technique is relatively new (Melbourne Water 2005a). The client for this project, Melbourne Water, has a suspicion that the land and grass filtration treatments that have been going on for many years at the WTP have led to a high salinity and contaminants in the soils caused by an accumulation in the paddocks (McGuckian 1997). Polluted soils do not perform the services they are able to in their natural state (Muneer 1999). Hence, it is very important to know the current state of the soil as well as the components of the wastewater being irrigated and how a possibly inappropriate application of wastewater can change the soil (Halliwell et al 2001) and lead to pollution off-site (Environmental Protection Authority 1983). Other challenges are future landuse changes and the need to make paddocks and treated water economically beneficial, rather than simply using fields as a place for wastewater disposal (Wrigley 2006a, pers. comm.) To accommodate this change, investigation of irrigation scheduling is of greatest importance. As the WTP is a part of a Ramsar Wetland Site, this task is even more challenging.

1.1. Aims and Hypotheses

The maize, Pioneer 38F70 (93 Siliage CRM) suitable for dryland short-season areas and irrigation situations (Pioneer Hi-bred Australia Pty. Ltd. 2006), was growing with various performances.

The purposes of this study were to see whether high salinity suppressed the growth of maize; or whether it was due to an improper irrigation scheduling; or nutrient stress.

The specific aims were to assess interactions between:

- growth performance of maize;
- salinity budget (electrical conductivity -EC);
- water budget;
- nutrient (N, P & K) budget; and
- pH

The hypotheses were:

- the current irrigation scheme is too infrequent and too much water is being applied at the same time;
- the current high salinity suppressed growth of maize; and
- the nutrient budget is improper

2. Literature Review

2.1. Western Treatment Plant: background and history

Melbourne Water is owned by the Government of Victoria and act as the company that manages Melbourne’s water, including the Western Treatment Plant (Melbourne Water, 2005a), which is located at 50 km south-west of Melbourne Central Business District (Muneer, 1999). The WTP is one of the world’s largest treatment plants. It is nearly 11000ha and processes 485 million litres of sewage a day, which accounts for 52% of Melbourne’s total sewage generated daily. For over a hundred years, since the establishment in 1897, the treatment plant has managed a large proportion of Melbourne's sewage (Melbourne Water, 2005a).

Throughout the years, different treatment processes have been applied. Stevens et al (2002) report that these processes include (i) land filtration (irrigation), (ii) grass filtration (overland flow) and (iii) lagoons. Due to environmental reasons, the lagoon system has been upgraded with the latest technology and the grass and land filtration were abandoned in December 2004 (Melbourne Water, 2005a).

2.1.1. Land filtration

Land filtration used to be the treatment that by far covered the largest area at the WTP. The method involved wastewater to pass through the soil and in that way filtrate solids and purify the water with natural mechanical, biological and chemical treatment. The wastewater moved around the system by gravity in pipelines and concrete lined channels and continued on to the bays. The bays were designed to let the water infiltrate and flow underground from one end of the bay to the other, where it drained out below the groundwater level. The watering was done for two days followed by five days of drying, after which the paddocks were grazed with livestock for about ten to fourteen days. This procedure was applied ten to twelve times a year in spring, summer and autumn when the evaporation was efficient (Muneer 1999).

2.1.2. Grass filtration

Grass filtration occurred on a smaller area and only in winter when the evaporation was not efficient enough with land filtration. As for land filtration, the wastewater was applied to the bays by gravity. However, this was primarily a biological process, where the wastewater applied travelled overland, instead of through the soil as in land filtration, letting the dense grass filtrate the solids. Therefore, it was not crucial for these soils to have favourable permeability properties, which was important where land application was practiced. On average, this process would take 36 to 48 hours (Muneer 1999).

2.1.3. The lagoons

When first introduced, the reason was to treat the extended wastewater which land and grass filtration were not efficient enough to treat during peak flows, i.e. not all the wastewater went through the lagoon system. There were series of eight to twelve lagoons for the wastewater to pass. Each of them were between four to eight hectares in size and about a meter deep, except for the first one in each series, which was about two meters deep to be able to handle the sedimentation and accumulation of solids. The wastewater stayed in each lagoon between three and twenty days before it moved on to the next one in line. The wastewater was treated by the natural process of sedimentation, aeration and by bacterial and algal activity (Muneer 1999).

2.2. Western Treatment Plant: today

The Environmental Protection Agency (EPA) Victoria required an environmental upgrade of the WTP, and in August 2000 it was agreed upon that Melbourne Water would minimise the waste generated at the WTP and intensify the extraction of contaminants from the effluent among other things. However, the most substantial outcome was the recycled water generated at WTP, which by 2010 is estimated to reach 30,000 million litres of water a year which is approximately 10% of the treated effluent produced at Melbourne Water’s sewage treatment plants, should contain less N (Melbourne Water, 2005b).

2.2.1. The lagoons

Since January 2005, after the upgrade, the three lagoons with anaerobic decomposition have been covered to catch the methane produced by the bacteria. This gas is now used to generate electricity to run the treatment plant, instead of spreading odour over an extended area. Nowadays, all the wastewater runs through the lagoon system before it gets pumped up to a chlorination plant and an UV plant for further treatment up to class B (Melbourne Water, 2005a).

2.2.2. Wastewater irrigation

Farmers will have a reliable supply if using wastewater for irrigation and the quality of the water can be assured to be satisfactory. They will no longer be dependent on the seasonal varieties that are associated with irrigation with water from the Werribee River (Beard 2005, pers. comm.) and in a country facing lengthily draughts, recycled irrigation water should be treasured. This has been shown to be important for farmers in Tunisia (Scott et al 2004). However, in general farmers are concerned and not yet entirely convinced that wastewater is good use for irrigation. There are contamination and over-fertilisation issues. These issues need to be carefully investigated and farmers need to be educated and trained to use wastewater for irrigation. Furthermore, extended information about the advantages and the possible risks with wastewater irrigation needs to reach the public (Scott et al 2004).

2.3. Soil: issues associated with wastewater irrigation

There is a common concern that wastewater generally contains more salts, metals and trace elements than other irrigation waters, e.g. surface waters. With time, these constituents may accumulate and cause contamination and problems with soil structure, hydraulic conductivity and plant growth among others. This is especially true for finer textured soils. A number of studies have been conducted regarding soil properties with changing salinity and sodicity levels in irrigation waters. Proper drainage, salt leaching and rising watertables are also issues of concern (Halliwell et al 2001; Slavich et al 2002; and Qian & Mecham 2005).

2.3.1. Sodic soils

Sodic soils contain high proportions of the cation composition as sodium (Na) compared to calcium (Ca) and magnesium (Mg) and are usually assessed through SAR (Sodium Adsorption Ratio). SAR is closely linked to ESP (Exchangeable Sodium Percentage) and easier to determine than ESP (FAO 2002)

The following equations, Eq. 1 (Sparks 2003) & Eq. 2 (Brady & Weil 2002) explain the chemistry of sodic soils:

$$SAR = ([Na+]/([Ca^{2+} + Mg^{2+}])/2)^{1/2}, \qquad \text{(Eq. 1)}$$

where the brackets indicate the total concentration of the ions (expressed in mmol liter^{-1}). Note that SAR is measured in total concentration and not activity and therefore does not include the decreases of free ion concentrations and activities that occur due to the formation of ion pairs or complexes.

$$ESP = \frac{\text{Exchangeable sodium, cmol}_c\text{/kg}}{\text{CEC, cmol}_c\text{/kg}} \times 100 \qquad \text{(Eq. 2)}$$

Soils are defined as sodic when the ESP >15 %, SAR >13, EC_e <4 dS m^{-1} and pH >8.5 (Brady & Weil 2002). Note that the value for ESP is true for the USA and many other countries. However, White

(2006) reports that the ESP value for sodic soils in Australia is >6 %, as water with less electrolyte concentration is used to assess the ESP threshold value.

2.3.2. Elevated values of EC, ESP and SAR

Qian & Mecham (2005) show that soils irrigated with wastewater, had a higher EC on average compared to soils irrigated with good quality surface waters (melted snow from the mountains). The wastewater irrigated sites had ~480% higher SAR value than the surface water irrigated sites, although Ca had been applied annually to prevent greater degree of Na build-up in the soil. A similar study by Surapaneni et al (2001) reveals the same pattern (figure 1).

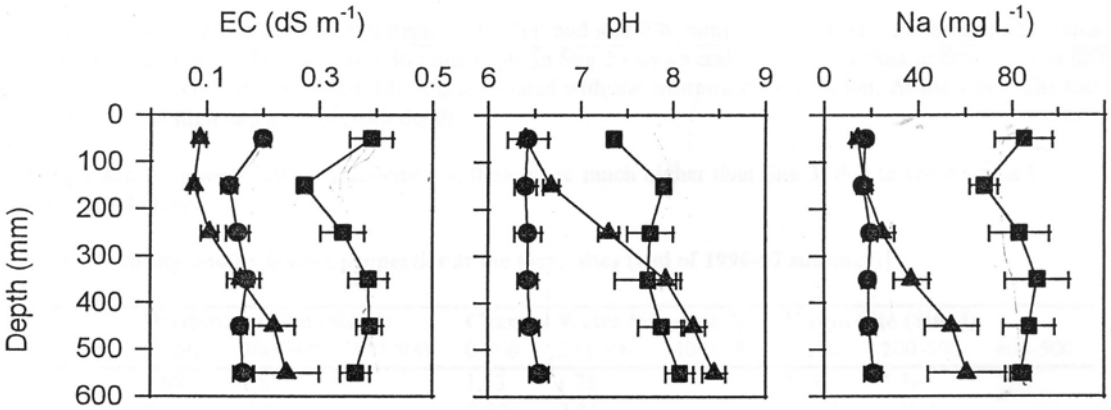


Figure 1. Depth distribution of EC, pH and Na at the saline-sodic wastewater irrigated site (■), non-saline non-sodic channel water irrigated site (▲) and non-irrigated reference site (●). Source: Surapaneni et al (2001).

2.3.3. Change of soil structure

2.3.3.1. Dispersion and swelling

Clay tactoids disperse when Na adsorbs to the outer surface of the tactoids, which occur when the ESP >15 and the salinity level is low (Essington 2004 and Sparks 2003), i.e. decreases below the critical flocculation value specific for different combinations of SAR:EC values (Halliwell et al 2001) (Figure 2). For dispersion to take place at low ESP values, to counteract crust formation for instance, energy input is required (FAO 2002. Swelling occurs when Na preferably adsorbs to the interlayers, which result in expansion of the tactoids and occurs when the ESP <15 (Essington 2004 and Sparks 2003). However, swelling would not occur as long as the EC of the applied wastewater increases with the SAR value (Halliwell et al 2001), which may be difficult to reach as the irrigation bays are open systems where rainwater will dilute the irrigation water hence dispersion and swelling can occur (Rendel McGuckian). However, the critical SAR:EC value that represents the borderline between stable and unstable state of the soil is unique for each soil type. The level at which Na may become a problem is also dependent on soil texture, clay mineralogy, organic matter content and the concentration of electrolytes other than sodium in the soil solution (Essington 2000), hence, figure 2 should therefore only be seen as a guideline (FAO 2002).

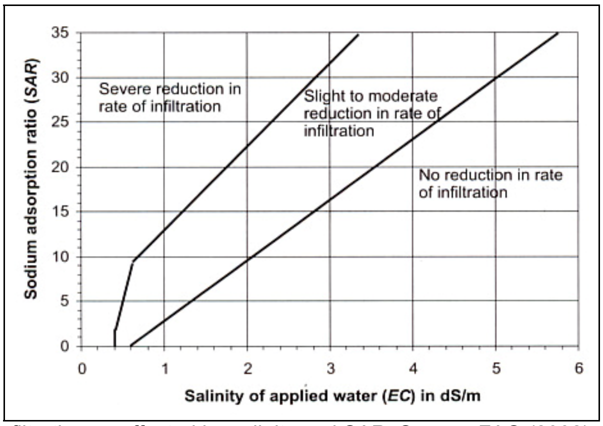


Figure 2. Relative rate of water infiltration as affected by salinity and SAR. Source: FAO (2002).

2.3.3.2. Effect on hydraulic conductivity and infiltration rates

Both dispersion and swelling change the pore volume (Halliwell et al, 2001), which has an effect on infiltration and can cause a crust formation (FAO 2002). If irrigation with an excess of sodium continues a long-term effect of a reduced hydraulic conductivity may occur, especially if carbonates are present in the water, because SAR increases when calcium carbonates precipitate (FAO 2002). The reduced soil hydraulic conductivity leads to poor soil physical structure and plant production due to poor abilities for root penetration, water infiltration and air movement into the soil (Halliwell et al 2001). There are also reports on excessive weed growth, nutritional disorders, water ponding and rotting roots as secondary effects of reduced hydraulic conductivity (FAO 2002).

2.7. Maize: issues associated with water, salt and nutirents

2.7.1. Life cycle

Maize is one of the most important crops in irrigated semi arid areas in the world, although it is sensitive to water stress (Cavero et al 2000) and therefore has considerable irrigation requirements in dry regions. Maize is best grown when the soil temperature is above 12C. This means that it is planted between October and March in southern Australia, which is adequate time for the crop to grow between 120 – 150 days as needed according to Pritchard & Moran (1987). Pritchard & Moran (1987) has chosen to describe the growth of maize in six stages (figure 3). Sowing to seedling emergence takes about 5-14 days and depends on soil temperature, moisture and aeration etc. Stage two takes 30-40 days and water and nutrients are very important as the tassel and cob begin to grow. Stage four is the pollination and flowering period and at stage five harvest for silage is appropriate.

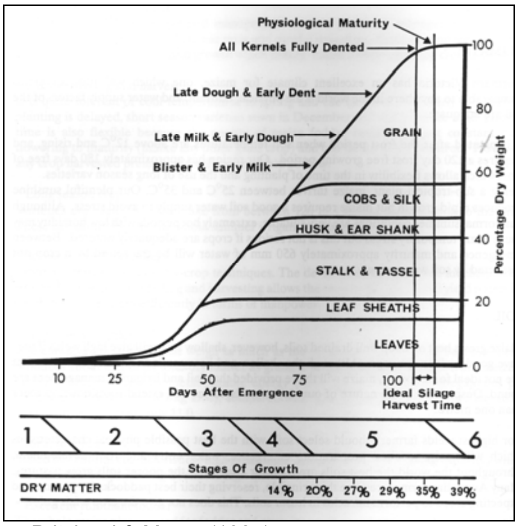


Figure 3. Maize growth stages. Source: Pritchard & Moran (1987)

2.7.2. Salt exclusion

Maize is moderately sensitive to salinity (FAO 1979) and therefore salinity can reduce the growth of maize and is by many authors (Munns 1993, Munns 2002 and Vetterlein et al 2004) explained as a two-phase response. The first phase is an effect of salt outside the roots rather than inside the plant, and is due to a decrease in the soil osmotic potential. According to Munns (1993), the roots sense the difference in solute concentration and hormonal signals regulate the reduction of shoot growth and the decline may be due to a water-stress rather than toxicity of salt at this stage. This was showed by Grant (1995), who reports that increased salt concentration of irrigation water reduced the osmotic potential and thereby also the maize water uptake, the evapotranspiration and also caused the phytomass yield to decrease. The second phase takes longer time to be visually noticed and occurs when the accumulation of salts in the transpiring leaf exceeds a level where it becomes toxic to the plant. The cells have then failed to compartmentalize salts in the vacuole, which is an important difference between salt-sensitive and salt-tolerant plants (Munns 2002). Failure of salt exclusion has been showed as necrotic older leaves (Fortmeier & Schubert 1995), a significant decrease in shoot yield (Muhling & Lauchli 2002) and substantial changes of protein regulations involving carbon and nitrogen metabolism (Zörb et al 2004). Furthermore, Muhling & Lauchli (2002), found an increase of Na^+ in the leaf tissue and a decrease of both Ca^{2+} and K^+ in a salt-sensitive cultivar.

To maintain a salt concentration in the soil where crop can grow and prevent an accumulation of salt, the salt input to the root zone needs to be equivalent to the salt output (Thomas 1991). Table 1 shows the yield potential at different salinities. In areas where the salt levels are too high to grow crop, reclamation of the soils is necessary to be able to grow crop (Brady & Weil 2002).

Table 1. Yield potential for maize (forage) growing in salt effected soils, all numbers showed in dS/m. Source: FAO (1984).

Yield potential							
100%		90%		75%		50%	
EC_e	ECw	EC_e	ECw	EC_e	ECw	EC_e	ECw
1.8	1.2	2.2	2.1	5.2	3.5	8.6	5.7

2.7.3. Water stress

Rooting depth, crop sensitivity of water and salinity are some of the factors that crop growth and yield depends on (Kahlown et al 2005). Frequency and depth of irrigations are two other important factors determining maize yield (FAO 1979). Farre et al (2000) show that yields may be reduced depending on timing and intensity of drought. During water stress, tassling and silking desynchronise leading to kernel abortion and a delay in grain setting. Vazquez-Montiel et al (1995) report a decrease in leaf area and thereby also reduced photosynthesis, leading to a significant reduction in maize grain yields when water deficits were exercised on the crop during the development stages. To mitigate these yield reductions, moisture availability is most important during flowering (Meija et al 2000) which includes tasselling, silking and pollination (FAO 1979). According to the same author, water-stress during formation may also cause reductions in yield. Maize appears to be relatively tolerant to water-stress during the vegetative and ripening periods, especially if the maize was subject to water deficits during the vegetative period. Water depletion up to 80% of soil available water during the first growth stages, where the ET is <6mm/day, may be advantageous as the crop may form roots more rapidly and deeper and, hence, will be able to be able to cope water stress in later stages. Liang et al (1996) suppose that the increased oxygen availability is the trigger for secondary root formation in drying soils. However, they also stress that too dry soil environments will have the opposite effect and so will an oxygen concentration of less than 5% have. Figure 4 shows how maize yield reflects water stress.

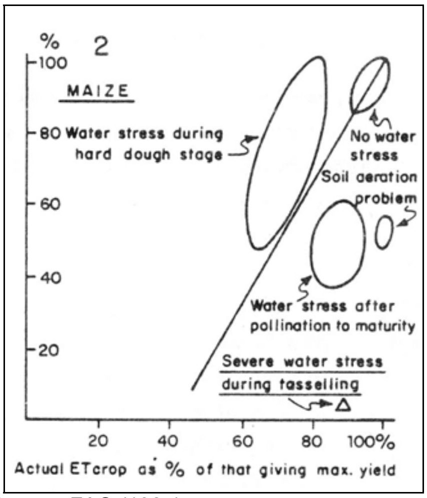


Figure 4. Maize yields and water stress. Source: FAO (1984)

2.7.4. Irrigation and leaching requirement

Border check flood irrigation has a distribution uniformity of 70-85% and a water application efficiency of 65-85% and an estimated deep percolation of 10-20% (FAO 2002). Still, monitoring the moisture levels in the root zone is highly suggested; not all the water is available to the crop (Figure 5). According to Lolicato (1999), the first irrigation after emergence should take place after 10 to 25 days after emergence of the crop, whereas FAO (1984) recommend the first irrigation to take place at or immediately after sowing as to flush excess salts away from the seed. If the intervals between the irrigation events are long and the soil is left to dry out, the EC levels in the soil solution become higher. This might cause both water- and salt stress to the crop and be direct toxic (Rendell McGuckian 1997). Hence, maintaining higher soil moisture helps avoiding crop stress and possible crop death. Additionally, salinity levels are unstable and do change during a cropping season on a monthly or even daily basis. These changes are important to know when planning drainage and irrigation scheduling, as they do affect crop growth (FAO 2002).

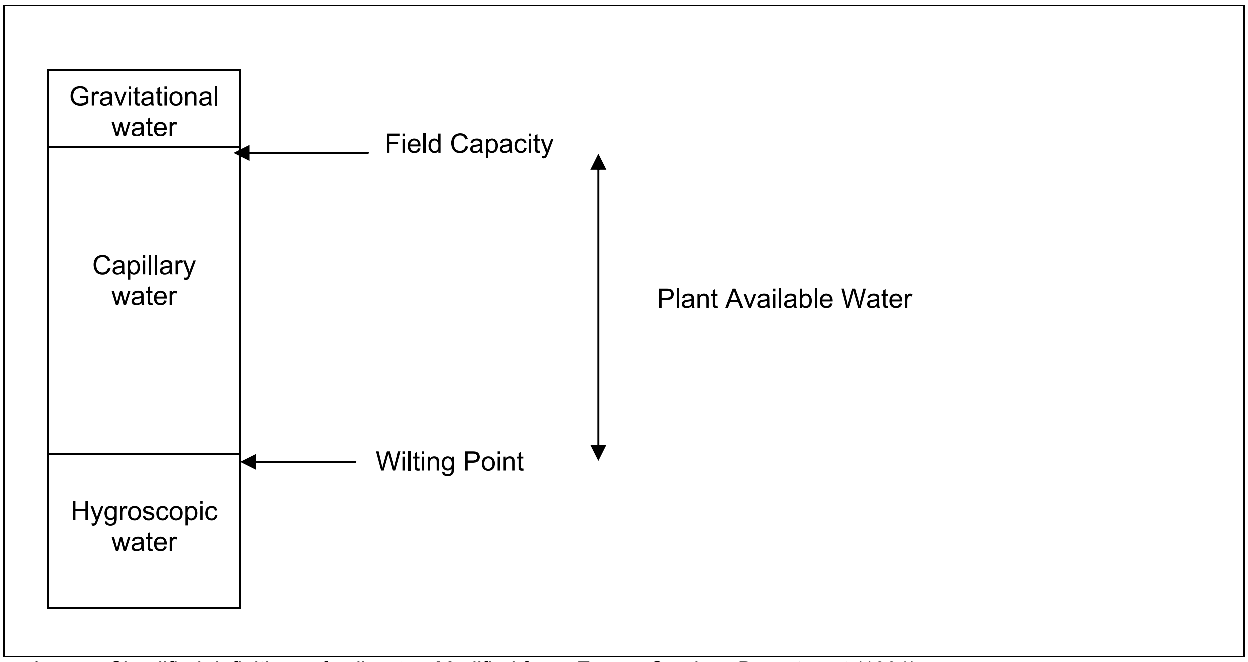


Figure 5. Simplified definitions of soil water. Modified from: Energy Services Department (1991).

Irrigation requirements should include leaching requirement (LR) and irrigation efficiency, e.g. amount of water available to the crop compare to the water received at the field inlet (FAO 1984). The actual LR for border check irrigation is suggested to be 1.3 times higher than the calculated LR as the irrigation in the field rarely matches the theory, i.e. some water goes to surface runoff and deep percolation (FAO 2002). However, Thomas (1991) mentions that leaching may not be necessary at each irrigation event, depending on crop salt tolerance and water salinity class. In addition, it is claimed that under some circumstances leaching during non-cropping periods will be enough to reduce the salt accumulated in the soil, which means that less irrigation water is needed during the peak-season (FAO 1984).

2.7.5. Waterlogging and water table management

Flood irrigation and waterlogging can cause soil aggregates to brake up and create a surface crust that makes it difficult for roots and water to penetrate (Pritchard & Moran 1987) and inhibit exchange of gases between the soil air and the atmosphere (Hillel 1978). High CO_2 levels and toxic products produced by anaerobic respiration have been reported (Mason et al 1987) as well as depletion of oxygen which can cause the seeds to easily rotten (FAO 1992). Experiments by Przywara & Stepniewski (1999) revealed that flooding can cause a decrease of root mass, plant height, biomass, leaf chlorophyll as well as root penetration depth. Mason et al (1987) report that maize roots can, however, cope with low oxygen concentration by developing new tissue, although, by doing that new shoot growth may be delayed. Nevertheless, waterlogged maize will have problems with N, P and K uptake as well as water uptake. FAO (1984) state that waterlogging during the flowering period can cause a 50% yield reduction or even more and Lolicato (1999) suggests that waterlogging is avoided during germination. This was demonstrated by Mason et al (1987), where flood irrigated maize ponded for 6 hours after each of the 12 irrigations ended up with 38% lower yield compare to the non-ponded treatment, i.e. 14t/ha and 22 t/ha respectively. The largest difference could be seen early after crop emergence.

As the soil dries up it forms a hard crust that cracks and can break the roots of seedlings and if the crust is particularly dense and thick, the only successful seedlings to emerge are the ones in the cracks (Hillel 1978). To prevent waterlogging, accurate drainage is crucial for irrigated lands (FAO 1992) as well as keeping the soils well-aerated (FAO 1984).

Many authors (Ayars et al 1999, Kahlown et al 2005 & Meija et al 2000) recommend certain distances to the groundwater table from the ground surface when growing crops on shallow watertables and that many crops can obtain a significant proportion of their requirements from the groundwater. This is sometimes referred to as Controlled Watertable Management (CVM) (Hornbuckle et al 2005). Meija et al (2000) show that a proper management of the watertable can improve the maize production by retaining more NO^{3-}, providing proper aeration and also keeping the groundwater within reach of the roots so that water is continuously available for the crop. Ayars et al (1999) reports on studies showing that maize growing within 0.6 m from a saline (6 dS/m) groundwater table and being irrigated by low salinity water, obtain 55 % of its water requirements from the groundwater. Similar studies by Kahlown et al (2005) show that about 40% of the maize water requirement was taken from the groundwater at 0.5m depth. However, the optimum groundwater level was found to be at 1.5-2m depth. In addition, Meija et al (2000) report of a higher maize yield compare to a free drainage plot when the watertable was managed properly and the watertable set at 0.75m. Larger grains and kernels were also found. FAO (1984) recommend a watertable at a depth of rooting depth plus additionally 40cm or 80cm for clay and loam, respectively. However, these figures are only a guide and not crop specific. Furthermore, they did claim that maize is sensitive to a groundwater level of 50cm or less. Additionally, FAO (2002) state that maintaining a shallow groundwater table reduces the drainage water and salt load discharged. However, before managing the watertable to control salinity and waterlogging, one has to bear in mind that a shallow watertable also induce capillary rise, which can lead to salinisation of the soil (Hillel 1982).

2.7.6. Drainage and porosity

In addition to a leaching fraction, effective drainage is needed to leach the salts out of the soil (Brady & Weil 2002). Abdel-Dayem (2006) emphasise that proper drainage of the subsurface is important if crop productivity is to be maintained and even enhanced and drainage should be designed so that advantageous moisture and salt concentration are held in the root zone. To manage drainage and water conservation, a thorough knowledge and stored data of hydrologic balance in the irrigated area is required (FAO 2002).

For proper crop growth air filled porosity is required. Under ideal conditions, where the total soil porosity is 50%, half of that would be air filled and the other half water filled. In general, air-filled soil porosity below 20% of total pore space, or 10% of the total soil volume, root respiration and hence crop growth become limiting and may result in waterlogging (Brady & Weil 2002). However, in a study on plant growth and air-filled porosity, da Silva et al (2004) concluded that maize was best grown when air-filled porosity was 0.15 – 0.20 cm^3/cm^3 (15-20%).

2.7.7. Nutrients

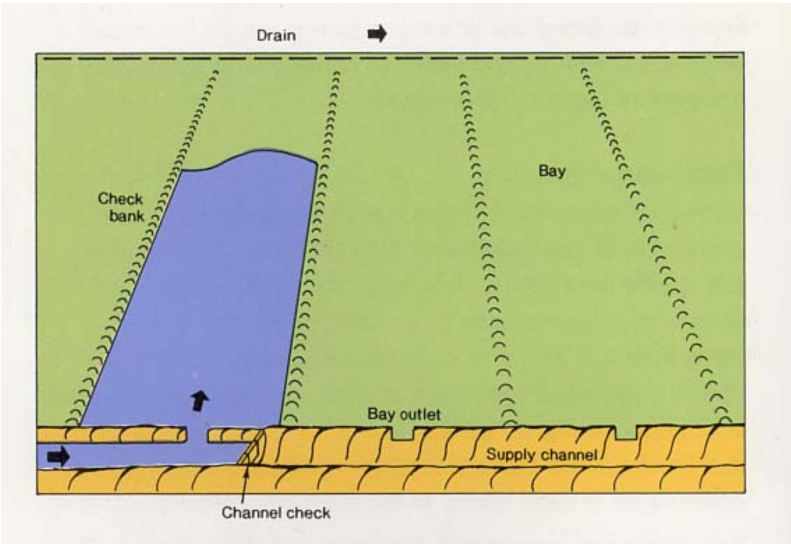
In maize, K is used in regulation of osmotic potential of cells and activates enzymes involved in respiration and photosynthesis. If deficient, leaf tips towards the base of the crop may curl, show chlorosis and eventually become necrotic and roots are more sensitive to root-rotting fungi. Ca is involved in synthesis of new cells and deficiency may give rise to short and brown roots among other things (Taiz & Zeiger 2002). Fortmeier & Shubert (1995) found signs of Ca deficiency in young leaves of maize and concluded that the transport of the nutrient had been harmed during water stress affecting leaf expansion. N is important in many parts of a plant cell, hence, if deficient it rapidly retards plant growth and may show as yellow/brown leaves at base of the stem while still green in younger leaves as the crop re-translocates N during deficiencies. Due to N deficiency, synthesis of amino acids will fall behind and leave carbohydrates in excess in the plant, which may be expressed as a woody stem (Taiz & Zeiger 2002).

3. Methodology

3.1. Site description

The four irrigation bays situated in two larger paddocks, C5 & C6, (appendix 1) were approximately 35 m across and approximately 420 m along. Paddock C5 contains of 4 bays at a total of 6.4 ha and paddock C6 contains 5 bays at a total of 8 ha. The irrigation bays are flooded at the top end of the bay and the water flows down the bay and out in drainage pipes at the bottom end (figure 6) .Two of the bays had better performing maize than the other two, thereby referred to as C5 good, C5 poor, C6 good and C6 poor. The soil material used was from the group of solodized Solonetz from the riverine planes of the WTP (Maher & Martin n.d.) which were sandy loam clay loam to clay loam.

Most of the ground was covered with weeds, sometimes up to 60cm tall whereas other parts of the ground had formed crusts with cracks and a large part of the maize had brown and yellow leaves at the base of the stem (appendix 2). The area has received effluent for at least 50 years according to the method described in section 2.1. and is known to have a shallow watertable (<1m). Landforming was done at the time of preparation of the bays many decades ago, as to level out the surface differences so that the water could run freely from the top to the bottom of the bay. Pre-cropping soil tests done by WTP staff are presented in Table 2.



a *b*

Figure 6. Illustration of a flooded border check irrigation bay (a), source: Pritchard & Moran (1987), and drainage pipes at the bottom of an irrigation bay (b), photo: Lina Peralainen.

Table 2. Pre-cropping soil tests shown as average values. Source: B James (2006, pers. comm.).

	C5	**C6**
EC (dS/m)	0.58	0.44
ESP (%)	17.1	13.2
pH	6.7	6.4

3.2. Site preparation and management

In mid-October 2005 knockdown spray was applied (Roundup ~2L/Ha, Wetter 125 mL/100L & Lemat 100 mL/ha) as the paddocks were very rough with clumps of fescue. Ten days later gypsum was sprayed at a rate of 5T/ha. The maize was sown on the 11^{th} of October 2005 with a double disc machine at a rate of 85,000 seeds/Ha and 60 kg/ha of monoammonium phosphate (MAP). There were difficulties with getting penetration with the machine and to regulate the seed flow. Roundup was then applied a second time (~1 L/ha) as a post sowing pre-emergent knockdown spray. The insecticide spray Astound, an alpha-cypermethrin with an active constituent concentration of 100 g/L, was applied against heliothis at a rate of 400 mL/Ha. The maize was harvested on the 17^{th} of March 2006. Note that no spraying for weeds was done after sowing. Table 3 and above figures and operations were reported by B James (2006, pers. comm.).

Table 3. Maize calendar operations. Source: B James (2006, pers. comm.).

Date	Operation
15/10/2005	Knockdown spray
25/10/2005	Gypsum spread
11/11/2005	Knockdown spray
13/11/2005	Maize sowing
22/12/2005	Insecticide spray
17/03/2006	Maize harvested

3.3. Available data used

Data on irrigation application (frequency and amounts) and water quality (salinity and nutrients) was collected from WTP staff member Ben James whereas climate data (rainfall, evaporation and evapotranspiration) was given by Adam Buzza (measured at a DPI weather station in the Werribee South Irrigation District adjacent to the WTP). The salinity, N and P data were taken from the water flow at the L55E site, which was measured on a weekly basis. The N was measured as NH_3, NO_3 and NO_2, where NO_3 is by far the most common compound, and therefore N is presented as a total of all N species. The evapotransporation was calculated based on air temperature, solar radiation at 2m, wind speed and relative humidity at 1.5m at the DPI weather station before given to me. These data were then used to calculate/analyse water and salinity budgets.

3.4. Water budget

For calculations of the current irrigation scheme, data of irrigation applications and the total area of the bays were used. For calculations of the suggested irrigation scheme, alternative 1, the following data were used: evapotranspiration; LR (equation 3); 100% yield potential from table 1; Available Water Capacity of 40mm (R Wrigley 2006b, pers. comm.); and suggestions by Energy Services Department (1991), i.e. multiplication with factor 1.43 and irrigation whenever 50% of the AWC is depleted. To really make sure that the soil was wet enough before sowing, the two first irrigations were larger than the following ones. This resulted in a total of 890mm, which is 250mm more than the current scheme. The roots in these bays were estimated to extend down to ~0.3m where the crop was short and ~1m for the healthy growing crop, however, in these examples the more opportunistic option was used.

$$LR = EC_{IW}/((5*EC_{ts}) - EC_{IW}) \qquad \text{(Eq. 3)}$$

where EC_{IW} is the EC of the irrigation water and EC_{ts} is the average EC of the saturated soil paste, which represents the acceptable level of growing a specific crop without a reduction in plant growth (FAO 2002).

3.5. Salinity budget

For calculations of salt input, estimations from the already existing irrigation application, salinity concentrations measured at site L55E and the total area of application were used. For the salt storage, calculations of the soil samples below were used and salt output was calculated using the input and storage data.

3.5.1. Soil sampling

On the 2nd of March 2006, 17 days after irrigation, 17 soil samples from each of the four bays (4*17 = 68 samples in total) were taken for measurements of EC and pH. The samples were taken in the middle of the bays (i.e. approximately 17.5m from both sides lengthways) and ~23 m apart at a depth of 0-10 cm. A soil auger with a diameter of 2.5 cm and 10 cm in length was used. Notes on height of the maize, distance between individual plants and whether the soil was bare or weed infested were taken for each sample.

3.5.2. Preparation of soil samples and measurement of EC and pH

All 68 soil samples were air-dried and the soil was grinded using a mortel and pestle to break up aggregates larger than 2 mm size. EC and pH was measured in a 1:5 soil:water extract according to Rayment & Higginson (1992). In order to show EC as the EC of the saturation extract (EC_e), which is a more accurate value of the salinity of the soil, the following calculation was done:

$$\text{Average } EC_{1:5} * \text{factor} \quad \text{(Eq. 4)}$$

Factor 9, based on the soil texture according to DPI (2005), was chosen for the surface soil as the texture was course and could therefore hold little water and hence the salt concentration was higher than it would be in a finer textured soil.

All measurements were carried out in duplicate and the mean values are presented.

3.6. Nutrients and yield

The nutrients received were estimated from the irrigation water quality data (section 3.3.) and used for calculations with irrigation application and the total area of the bays. The nutrient requirements were extracted from literature (FAO 1984). During soil sampling, crop height was also measured as a parameter of yield and yield potential data was taken from the literature (FAO 1984; Brady & Weil 2002; and Zörb et al 2004).

4. Results

4.1 Water budget

Climate data from the DPI weather station, in the Werribee South Irrigation District adjacent to the WTP, paddocks C5 and C6 at the WTP during the cropping season of 2005/2006, shows a very large water deficit from October 2005 to March 2006: 932mm water deficit if rainfall is considered and 1132mm if the effective rainfall is considered (Figure 7). This difference is what is needed to be applied by irrigation to keep the soil moisture more or less unaffected. The definition of effective rainfall in this case is that rainfall <5mm is regarded as nil, 5.1-12mm as 50% and effective and >12.1mm as 70% effective. This is based on the theory that parts of the water is evaporated, regarded as runoff or deep percolation (Wrigley & Botta 2003) and that a decent amount of rainfall is required before the water actually trickle down through the profile towards the groundwater instead of being evaporated, as it does in the case of a small rainfall. No attention is given to the possible differences in soil characteristics between the bays.

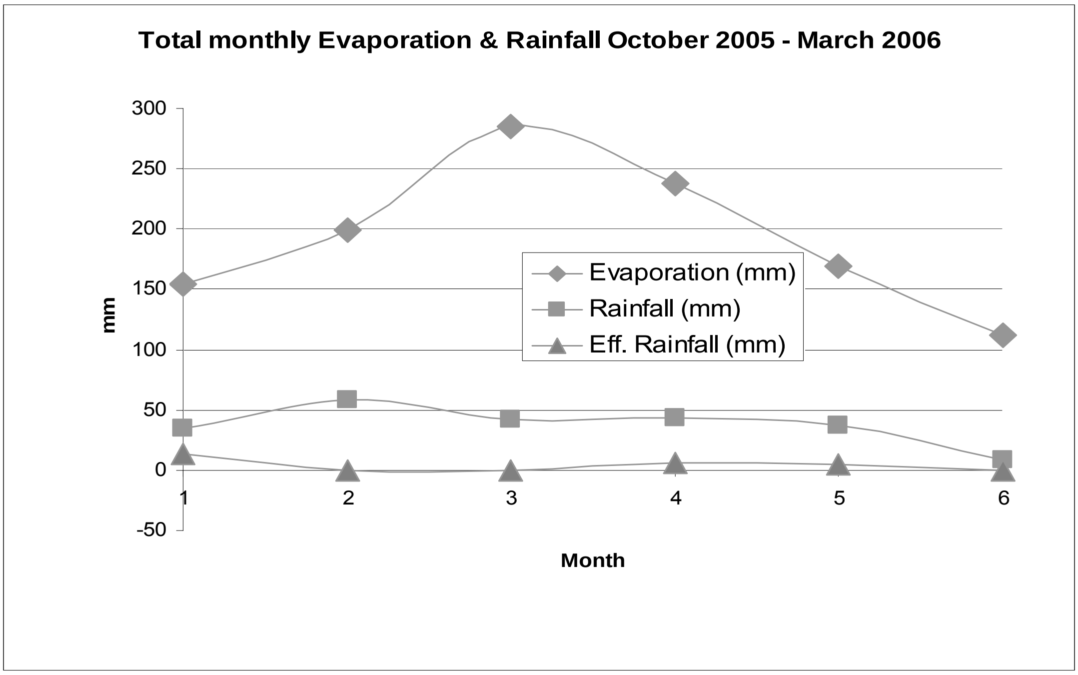


Figure 7. Total monthly evaporation and rainfall for the growth season of 2005/2006. Data was measured at the DPI weather station in the Werribee South Irrigation District adjacent to the WTP.

The difficulty is to know how much and how often the maize should be irrigated. The irrigation events from the growing season of 2005/2006 (figure 8), reveals an irregular scheme in time, whereas the amount applied is rather constant. In mid October and again 55 days later, in mid December, the paddocks were irrigated with 94mm each event. The six last irrigation events 75mm of water was applied and occurred with 8 -13 day intervals. After each of the eight irrigation events the bays were ponded with water for approximately 6 hours (R Wrigley 2006c, pers. comm.).

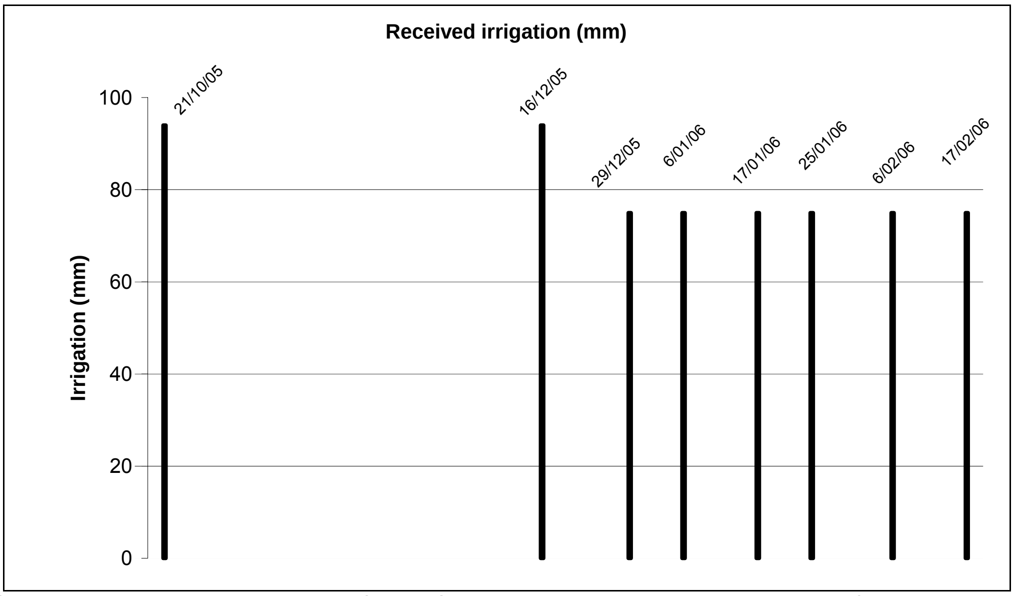


Figure 8. Current irrigation scheme at paddocks C5 and C6 at the WTP during the cropping season of 2005/2006.

With such a scheme, there was a moisture deficit in the soil for most of the time between the different irrigation events in relation to potential evapotranspiration. The deficit is shown as the effective rainfall subtracted by the evapotranspiration. The soil conditions between irrigations are showed in Figure 9, where A) illustrates the water deficit between 16/12/2005 and 28/12/2005 and B) demonstrates the period between 29/12/2005 and 5/01/2006. On day five between the third and fourth irrigation event there was a rainfall effective enough to give a theoretical surplus of ~4mm in the soil.

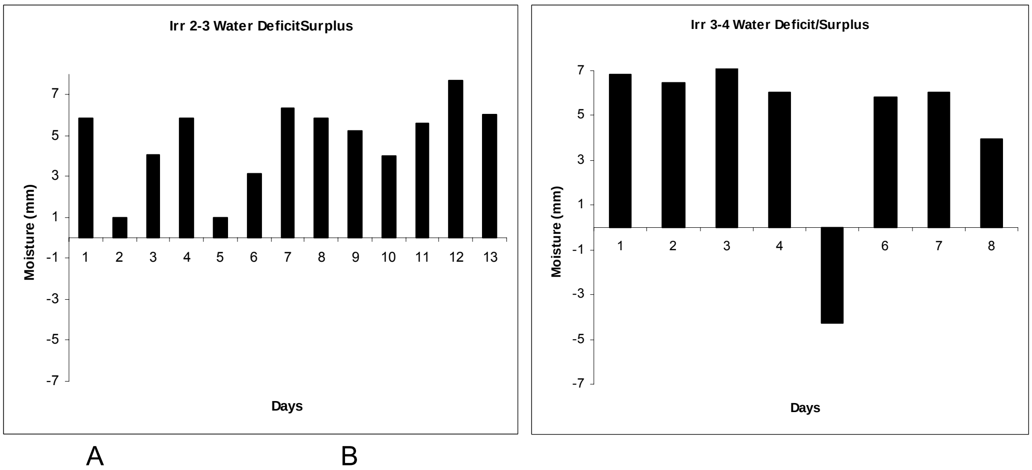


Figure 9. Variations in soil moisture at paddocks C5 and C6 at the WTP between irrigation events A) 2 & 3 and B) 3 & 4.

As described in section 3.4., the suggested irrigation scheme throughout the growing season of 2005/2006 for the paddocks C5 and C6 at the WTP was 36mm for each of the 24 irrigation events which took place whenever 50% of the AWC was lost (figure 10).

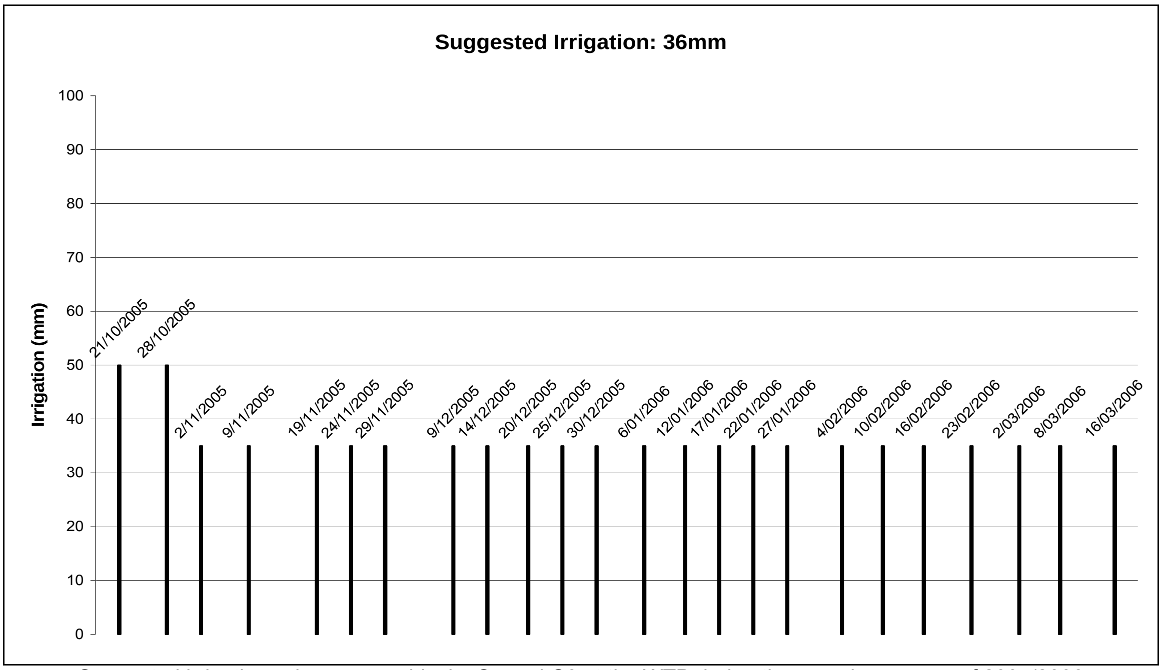


Figure 10. Suggested irrigation scheme at paddocks C5 and C6 at the WTP during the cropping season of 2005/2006.

4.2. Salt budget

Figure 11 shows the magnitude of A) soil salinity and B) crop height throughout the bays. The average EC_e in the bays were: C6 Good 1.61 dS/m; C6 Poor 1.82 dS/m; C5 Good 1.37 dS/m; and, C5 Poor 1.75 dS/m. The average heights in the bays were: C6 Good 1.62m; C6 Poor 1.41m; C5 Good 2.32m; and C5 Poor 1.82m. C5 Good had the lowest salinity overall, except for a large value in the middle of the bay. All bays except for C6 Poor had higher salinity at the top end of the bay than the bottom end of the bay. Height does not show a pattern all; C6 Good were tallest at the top end, whereas C5 Good and C5 Poor were tallest at the bottom end and C6 Poor tallest had the tallest crop in the middle of the bay.

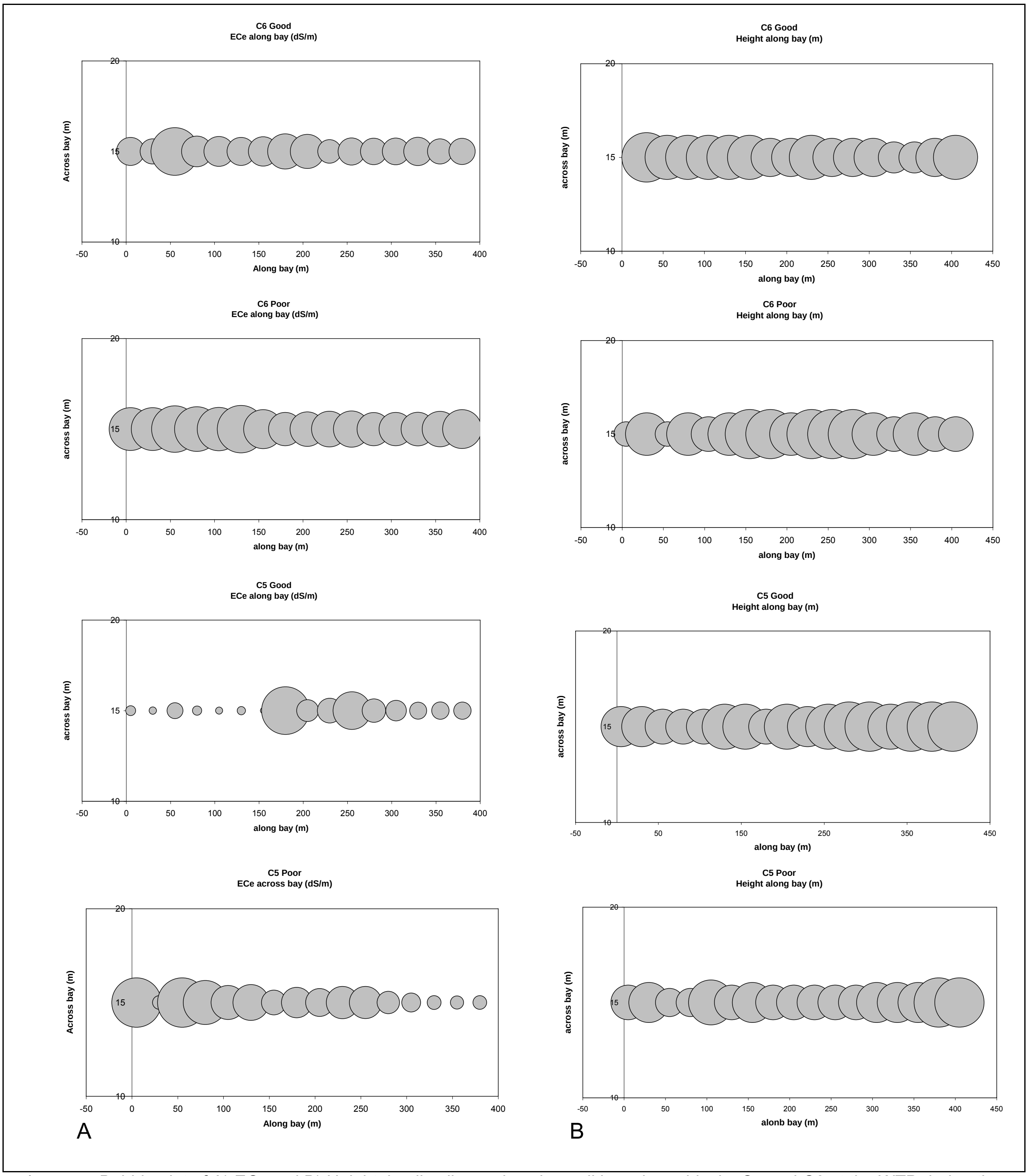


Figure 11. Bubble plot of A) EC_e and B) Height, in all soil samples along all bays in paddocks C5 and C6 at the WTP during the cropping season of 2005/2006. The size of the circles reflects magnitude of value.

The average values of the soil samples taken for measurement of EC_e was plotted against the average height of the maize adjacent to the place of sampling (figure 12). In field C5 Good looked like it was performing better than all other bays and the data verifies the notion. The graph shows that the best performing bay, C5 Good, had the lowest salinity and also the tallest crop. However, the correlations between height and EC_e for each soil sample in all the bays were non-significant. The R^2 values for the bays were C6 Good 0.02; C6 Poor 0.28; C5 Good 0.03; and C5 Poor 0.44.

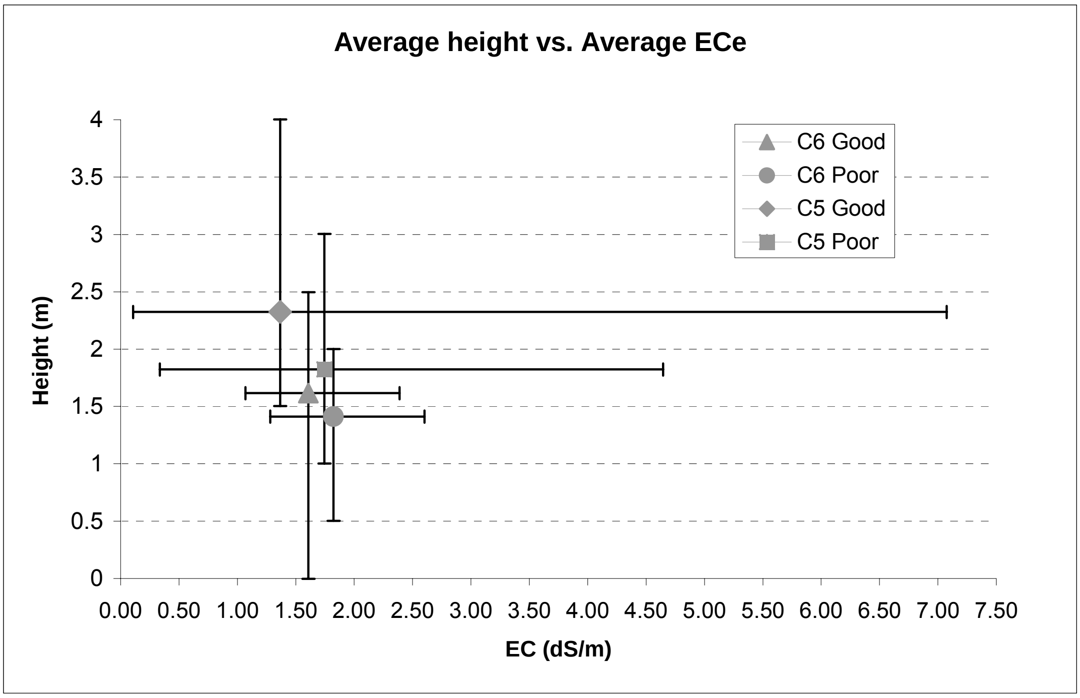


Figure 12. Average height vs. average ECe in the bays of soil sampling in paddocks C5 and C6 at the WTP during the cropping season of 2005/2006.

Throughout the cropping season of 2005/2006, the mass salt received by irrigation was calculated to be 95.5 tonnes (based on the water salinity (mg salt/L water), irrigation applications and total area of the bays) and the salt still present in the surface (calculated from the soil samples taken from 0-0.1m) was 11 tonnes (figure 13).

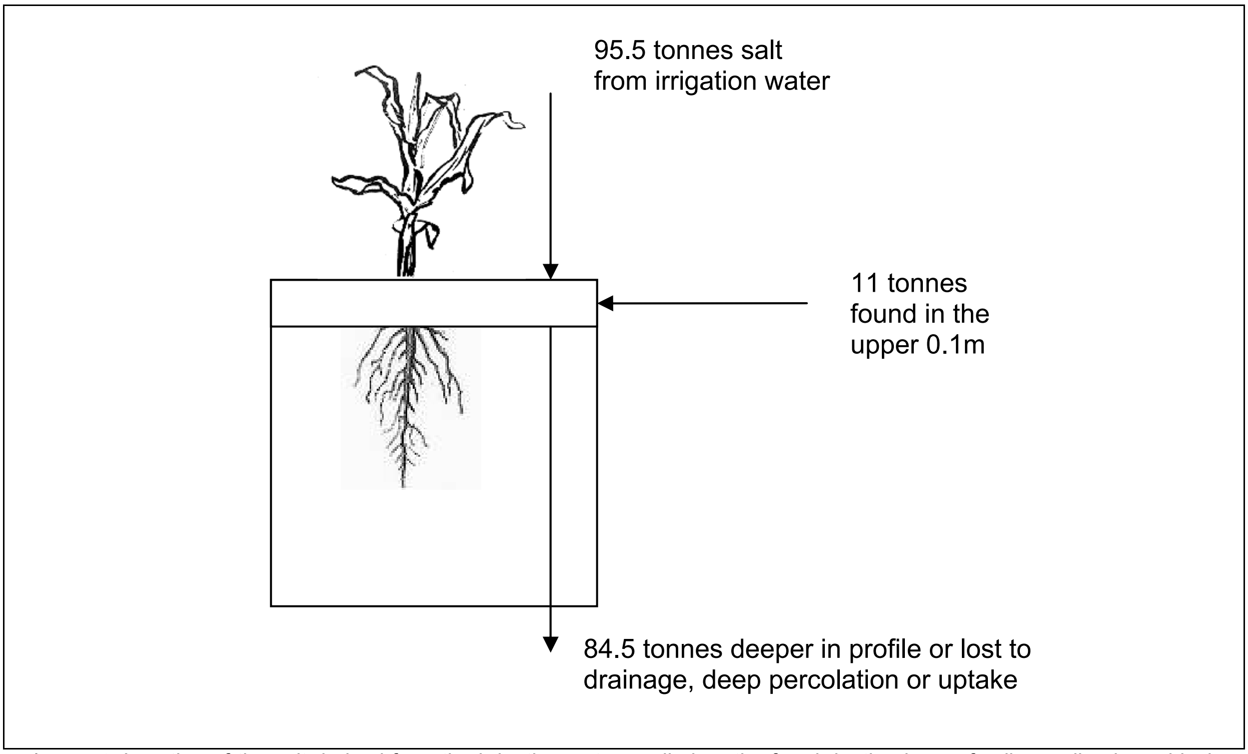


Figure 13. Location of the salt derived from the irrigation water applied on the four irrigation bays of soil sampling in paddocks C5 and C6 at the WTP during the cropping season of 2005/2006

4.3. pH

The pH ranged between 5.85 in C5 Good to 8.35 in C6 Poor, except for C5 Poor, which had samples in the middle of the bay that had values as high as 17.95 and then gradually lower values again (Figure 14).

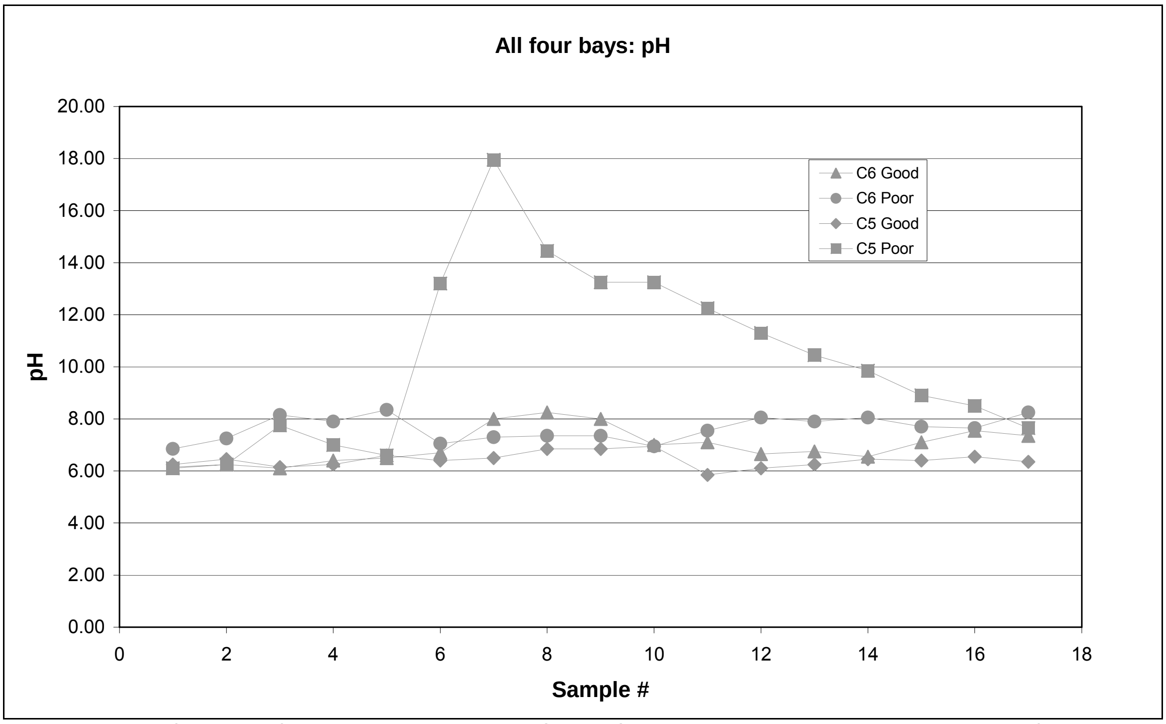


Figure 14. pH in the four bays of soil sampling in paddocks C5 and C6 at the WTP during the cropping season of 2005/2006
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4.4. Nutrients

The estimated nutrients received and the approximate nutrient requirements according to FAO (1984) are showed in table 4. The received N and P are within the recommended range but K was applied in almost double the dose required.

Table 4. Table of estimated received nutrients and approximate nutrient requirements. Source: a) Site L55E at the WTP; b) Site HORS at the WTP; and c) FAO 1984

Nutrient:	Est. received Kg/ha/annum	c) App. Requirement Kg/ha/annum
Nitrogen (N)	a)142	100-200
Phosphorus (P)	a) 65	50-80
Potassium (K)	b)170	60-100

4.4. Yield

In this study, yield was measured by average cob mass at the time of harvest. Unfortunately, there was no separation made between the different bays in the two paddocks, only between the two paddocks. The yield in the paddock C5 was estimated to 7.1 tonnes DM/ha and in C6 to 6.5 tonnes DM/ha. In total, the yield was 97.5 tonnes. However, during sampling, measurement of crop height was taken as a parameter of yield.

Table 5 shows the percentage of the samples that had a potential yield of 90 or 100%, respectively, depending on the EC_e based on various literature sources (a - d) as well as the yield measured at time of sampling (e & f). For instance, based on Brady & Weil (2002), C6 Poor should have had a 90% yield, as 100% of the soil samples taken were <4dS/m and based on FAO (1984) the well performing bays had 88% and 94% chance, respectively, to have a 100% yield, whereas the corresponding figures for the Poor bays were 82% and 88%, respectively.

Table 5. Potential yields in the four bays of soil sampling at the paddocks C5 and C6 at the WTP during the cropping season of 2005/2006, based on various sources.

	EC				Height	
	100%		90%		100%	90%
	a) FAO 1984 (%)	b) FAO 1984 (%)	c) Zörb et al 2004 (%)	d) Brady & Weil 2002 (%)	e) Yield (%)	f) Yield (%)
C5 Good	82	88	88	88	77	51
C6 Good	82	88	94	94	54	60
C5 Poor	59	76	82	88	61	67
C6 Poor	59	76	88	100	47	52

a) <1.8dS/m; b) <2.2dS/m; c) <2.5dS/m; d) <4.0dS/m; e) Based on crop height of 3m throughout a bay was valued as a 100% yield; and f) Based on 90% of e) and valued as a 90% yield.

5. Discussion

The present study did not have the resources necessary for a proper investigation of the maize in paddocks C5 and C6 at the WTP. The parameters investigated and the extensions of the work were too few to be able to show why performances in maize yield in the four bays differ from each other. However, some indications and trends can be reported.

5.1. Landforming

Laser grading, done with a tractor and a ground-flattening machine, followed by landforming was done at the WTP (Wrigley R 2006, pers. comm. 2 March) to smooth the surface, provide filling for the border checks and to apply a certain gradient on the bays (Energy Services Department 1991). Both processes are likely to have modified (removed and buried) the valuable topsoil (Wrigley R 2006, pers. comm. 2 March). The desire to create uniform bays for efficient irrigation applications may have failed, causing poor drainage and depressions on the flatter areas causing water to remain long after the irrigation, perhaps even for days. Additionally, soil aggregates were probably mechanically broken up and the soil compacted due to the heavy machinery used for the laser grading (Energy Services Department 1991). Studies by Akanda et al (1991) have showed that laser graded soils had lower water holding capacity and porosity as well as higher density than soils in a control field. As a consequence, the soil was less aerated and therefore suppressed root growth, which lead to decreased maize growth. They, too, mention compaction of the soil as a valid cause for retarded growth. These scenarios are very likely to have happened at the WTP as well.

5.2. Irrigation and maize water requirement

When considering the texture of the soils at the WTP alone, the Available Water Capacity (AWC) would be ~150mm (Rowell 1994 & WTP Soil Maps). However, as the soil has been subject to pollution for a number of years, this soil is deteriorated and was estimated, based on earlier soil investigations of sodic soils at the WTP, to have an AWC as low as ~40mm (Wrigley 2006d, pers. comm.).

The input (rainfall & irrigation) should be equal to the output (ET, runoff, LR & deep percolation). At the WTP, the total potential soil moisture deficit during the growing season was 1132mm and the total irrigation was 638mm (figure 8). When accounting for leaching requirement and irrigation inefficiencies, the total irrigation should have been 1471mm (1132*1.3), which means that the bays lacked 833mm and should have been irrigated with more than twice as much as the actual irrigation. In fact, FAO (1979) claims that depletion of AWC down to 8mm during the first periods of maize development could be advantageous. However, at the WTP, the moisture deficit was 56-119mm, i.e. 64-127mm short of the borderline recommendations, which would have been a harsh environment for the young crops.

Realising the irrigation scheme at the WTP has to change, data and recommendations described in section 3.4 were used for irrigation suggestion alternative 1 (figure 10). However, 24 irrigations over a period of 22 weeks are a lot of irrigations and the amount of irrigation is rather low, 36mm per irrigation. Nevertheless, if the poor soil structure and the low AWC are to be considered, that is the appropriate irrigation scheme. For a 90% yield, according to FAO (1984) and according to Brady & Weil (2002), the irrigation should have been slightly less, 34mm and 31mm, respectively. Still, the amount of irrigations would have been the same as when irrigating with 36mm. Note that the irrigation suggestions presume that all bays are equal in respect of soil characteristics, which is not the truth. Additionally, as retarded crop will not utilise the estimated water requirement it may become waterlogged, grow even poorer and the soil becomes bare or close to bare which allows more capillary rise and evaporation and even less will grow in the salty environment created. Taking the complicated situation at the WTP even further and including the shallow groundwater table and a risk of extended capillary rise, soil surface evaporation and salinisation, further calculations/models have to be made and for that extended field data is required.

Translating the suggestions on irrigation timing by Lolicato (1999) to the present study, the first irrigation should have taken place between 28/11/05 and 13/12/05 whereas, when following the recommendations by FAO (1984), the irrigation should have taken place even earlier, on 13/11/05. However, the actual irrigation was not done until 16/12/05 which means that it was at least three days too late or as much as 36 days too late. By that stage, 161mm had evaporated from the soil and only 48mm of effective rainfall had been received since sowing on 13/11/05. As the soil is assumed to have an AWC of 40mm, the soil was probably very dry and the maize was not able to get the water required.

The irrigation dates suggested for 36mm were four days before sowing as to moisturise the soil and then again six days after sowing since there was an effective rainfall of 24mm the day after sowing and it was irrigated when 50% of the AWC was depleted. The suggested date for 50mm was on the day of sowing, when 80% of AWC had been depleted, despite the rainfall the following day (figures 10 &11). The difference between the current total irrigation amount and the suggested total amount will have no complications as far as abundance of water is concerned, as the water is recycled.

Pritchard & Moran (1987) points out maize growth stages two and four as periods where crop available water is very important. These stages fall between 24/11/05 and 29/12/06 (stage 2) and 25/1/06 and 1/2/06 (stage 4). During stage 2, 176mm were potentially lost to evapotranspiration and only 23mm gained through effective rainfall, which makes the deficit 153mm. The total irrigation during the same period of 35 days was 169mm, which is too little if it would have been a healthy soil with an AWC of ~150mm but too much for the soil at WTP. According to Lolicato (1999), the yield reduction can be 6-8% per day if crop water demand during tassling (stage 2) is not met. During stage 4, the deficit was 23mm and irrigation of 75mm on one occasion was applied, an amount that was far too much for this soil.

5.3. Roots

Root development is strongly reflected by soil structure, texture, location of the watertable as well as by rainfall and irrigation events (FAO 1979). Other reports (FAO 2002) have showed that in frequently irrigated environments roots tend to stretch towards the surface. However, at the WTP the irrigation was done infrequently and the groundwater level is rather shallow (<1m), hence, the roots may have strived towards the groundwater instead. The root depth in this study was estimated to be ~0.3-1m, whereas the typical value is 1-1.7m for mature maize (Rowell 1994) or 0.6-0.95 according to Energy Services Department (1991). The short roots may have been an effect of rotten roots due to reduced hydraulic conductivity (section 2.3.3.2.) or the dry environment that were present during lengthily times between irrigations (section 5.2.) or perhaps the anaerobic conditions that appear during waterlogging was a contributory reason. During waterlogging roots may have had, as contradictive as it sounds, problems with water uptake (section 2.7.5.), which could have delayed root growth. Furthermore, compaction of the soil from machinery (section 5.1.) and a poor structure due to high Na content (section 2.3.3.) are also plausible causes for the retarded roots.

5.4. Salinity, sodicity and pH

As the soils at the WTP have been exposed to raw effluent and poor quality irrigation water at an earlier stage, the comparatively good quality irrigation water that is used today at EC levels of 1.56-1.72dS/m is more likely flushing down the accumulated salts that previous treatments caused. Therefore, the examples in section 2.3.2. are not adaptable to the WTP. The salt found at the surface is most likely derived from capillary rise and accumulated in the surface in the drying environment. The great variations in salinity within a bay (Figure 11) may depend on the uneven conditions described in section 5.1.. Due to those indifferences, the groundwater table may have been at different depths throughout the paddock, which would have had an impact on how severe the action of capillary rise was. As no deep profile samples could be taken, there was no evidence of where the missing 84.5 tonnes salt could be located. However, other reports done at the WTP (Wrigley 2006e, pers. comm.) show that the salinity generally increases with depth. Therefore, one can suspect that the salt was lost to drainage, deep percolation or crop uptake (figure 13). Furthermore, the soil was most likely dispersing as the ESP values before sowing were >15 (>6) and the irrigation water and the upper part of the profile had rather low salinity.

As mentioned in section 5.3., during draught, roots may have got their water from the groundwater, which could have been saltier than the irrigation water as it had infiltrated through the profile and likely picked up more salts. Hence, the crop water uptake would have been of worse quality than first thought and therefore greater affected by salinity. However, in this study groundwater parameters were not taken, which, should be of interest in the future if a detailed knowledge about crop water uptake and quality is desired. Furthermore, the plants at the WTP might have experienced higher salinity levels than recorded at the time of sampling at the end of the growing period (2.7.4.). On top of that, the may have experienced water stress due to reduced osmotic potential in the early stages (2.7.2.) or to a higher salt concentration as the soil was left to dry out (2.7.4.). The yellow leaves may be an indication of the salt toxicity.

The absence of maize and the relatively low EC_e, at the top end of bay C6 Good suggests that there was something else than high salinity that inhibited maize growth. Possible reasons are high SAR/ESP (figure 2) or waterlogging, as this is the area which, in theory, is waterlogged for the longest period at every irrigation event. The poor correlation between height and EC_e (section 4.2.) also suggests that high salinity alone does not retard the growth of maize. Matching the pre-cropping ESP (table 2) with figure 2, figure 12 and pH it suggests that the sodicity at these bays range from a severe to no reduction in rate of infiltration, the lowest EC areas being the most severe ones. Neither the EC nor the height did show and indication of relation to the high pH in C5 Poor. Possible causes to the extremely high values may be due to a high ESP (Brady & Weil 2002) or to an error of the pH meter used, where the former is the most likely scenario.

5.5. Crusts, hydraulic conductivity and waterlogging

In the dry conditions between irrigations, crusts were most likely present, as mentioned by Hillel (1982) and Pritchard & Moran (1987). It would have been difficult for seeds to penetrate the crust, for water to infiltrate and gases to exchange in other places than in the cracks. A lot of the water was probably ponding before it eventually contributed to runoff or deep percolation and was in no or little use to the crop.

According to FAO (2002) in section 2.3.3.2. reduced hydraulic conductivity can lead to a number of disadvantages for crop growing in such an environment. Weeds are one problem. No spraying for weeds was done after sowing and the weeds could grow tall (appendix 2) and were most likely competing for water and nutrients, and perhaps even light when the maize was still short. The crop at the WTP may also have experienced waterlogging due to the reduced hydraulic conductivity and subsequently a low oxygen environment. However, chemical, biological or mechanical management (FAO 2002) could counteract the crusts and minimise these problems, e.g. application of gypsum, incorporation of organic matter and cultivation.

5.6. Drainage and watertable management

The shallow watertable at the WTP necessitates a better drainage and perhaps even controlled watertable management (CWM). By using this methodology waterlogging of the sensitive crop can be avoided and N deficiency would be a less pronounced problem. Additionally, the crop would automatically be encouraged to use the groundwater in between irrigation events and in that way save water which could be used in other areas. However, the down side is a possible enhanced capillary rise and salinisation, which should be avoided on these soils. Drainage water quality should be known and managed thereafter as to avoid pollution of surrounding water systems (Environmental Protection Authority 1983). This is of great importance as a part of the WTP obeys under The Ramsar Convention on Wetlands (The Ramsar Convention on Wetlands, 2004).

5.7. Nutrients

Along with the irrigation water, nutrients were distributed seemingly evenly as the same amount of water was distributed in all bays and they had been made even by laser grading and landforming. However, the topography and horizon differenced discussed above may have had an impact on nutrient availability as well. As stated in section 2.7.5., waterlogging will retard N, P and K uptake and an increase of Na in the tissue can cause a shortage of both K and Ca in the leaf (section 2.7.2.). At a first thought, one may believe that crop watered with wastewater would not have a problem with nutrient deficiency, however, as stated above, it is apparent that secondary effects of wastewater irrigation can have an impact on nutrient uptake and subsequently crop growth. Maize growing in the sodic soils of WTP may well have suffered from a shortage of N, P, K and Ca showed as yellow/brown leaves at the base of the stem, short roots and poor growing crop despite enough application of nutrients (table 4). However, note that N is mobile and is easily lost to weed uptake, nitrification and denitrification, which most likely took place in the channels between the site of measurement (Site

L55E) and the bays. Therefore, the crop probably received less N than the 142kg/ha/annum estimated, stated in table 4.

5.8. Yield

An average maize yield in Victoria is 20-28 tonnes DM/ha (Pritchard 1987) but at the WTP the yield was as low as ~7 tonnes DM/ha. According to table 5, the Good bays should have had a yield of ~80% and the Poor bays at least 60%. Judged by looking at it at the time of sampling (14 days before harvest), C6 Poor certainly had a yield less than 60%. The crop was short and in many places far apart, further than the rows 0.5m apart that they had been sown. Hence, there must be other causes that reduced the crop yield. According to (Mason et al 1987), the variations in growth may be due to differences in soil conditions, i.e. well-growing individuals may have been placed in a favourable spot and therefore grew well. Furthermore, experiments show that the state of an individual crop before the first irrigation can predict the final yield; large healthy maize before the irrigation was the dominant ones also after the irrigation. Considering the differences within the bays discussed in previous sections, these statements are valid.

6. Conclusion

As the four bays seemed to be identical and treated with exactly the same methods, i.e. irrigations, pesticide etc., my aim was to determine whether the obvious variations in the growth performance of maize in the paddocks C5 and C6 at the WTP were due to high soil salinity, improper water management or a nutrient disorder. I used water- and climate data from the WTP and DPI weather station in the Werribee South Irrigation District and soil samples from paddock C5 and C6 at the western end of the WTP.

I found an irrigation management that was not linked to anything; the water was simply applied whenever, creating either too dry or waterlogged environments. The surface salinity was low in general and should not have had a severe effect on crop growth. I did not measure SAR at all or EC with depth. Nor did I investigate the soil water fluctuations with tensiometers or other instruments and the nutrients were only looked at briefly.

A goal for the WTP is to produce high quality and quantity of crop in an environmentally friendly and resourceful way, which could be met by monitoring of pH as well as inputs and outputs of water, salt (EC, SAR), nutrients (N, P, K & Ca) and trace elements that could become toxic. These actions are essential for healthy crop growth. This should be done not only on the surface, but also through a deep profile. Furthermore, climate data, crop water demand and soil AWC should also be incorporated and assessed to accommodate any changes in the irrigation schedule and management of the bays. Simple models could do this. Effective drainage is crucial in this type of soil and it should be of interest to oversee the groundwater table fluctuations and the soil water, perhaps with tensiometers. Lowering of the groundwater table should be done as to moderate capillary rise and further salinisation. Application of gypsum and incorporation of organic matter should be done to improve the soil structure. The high ESP/SAR and the consequences it leads to are probably the largest problem at the WTP which together with the shallow watertable create an inhabitable environment for maize.

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- Adam Buzza, DPI, Victoria, Australia
- Claire Dixon, Melbourne Water, Melbourne, Australia

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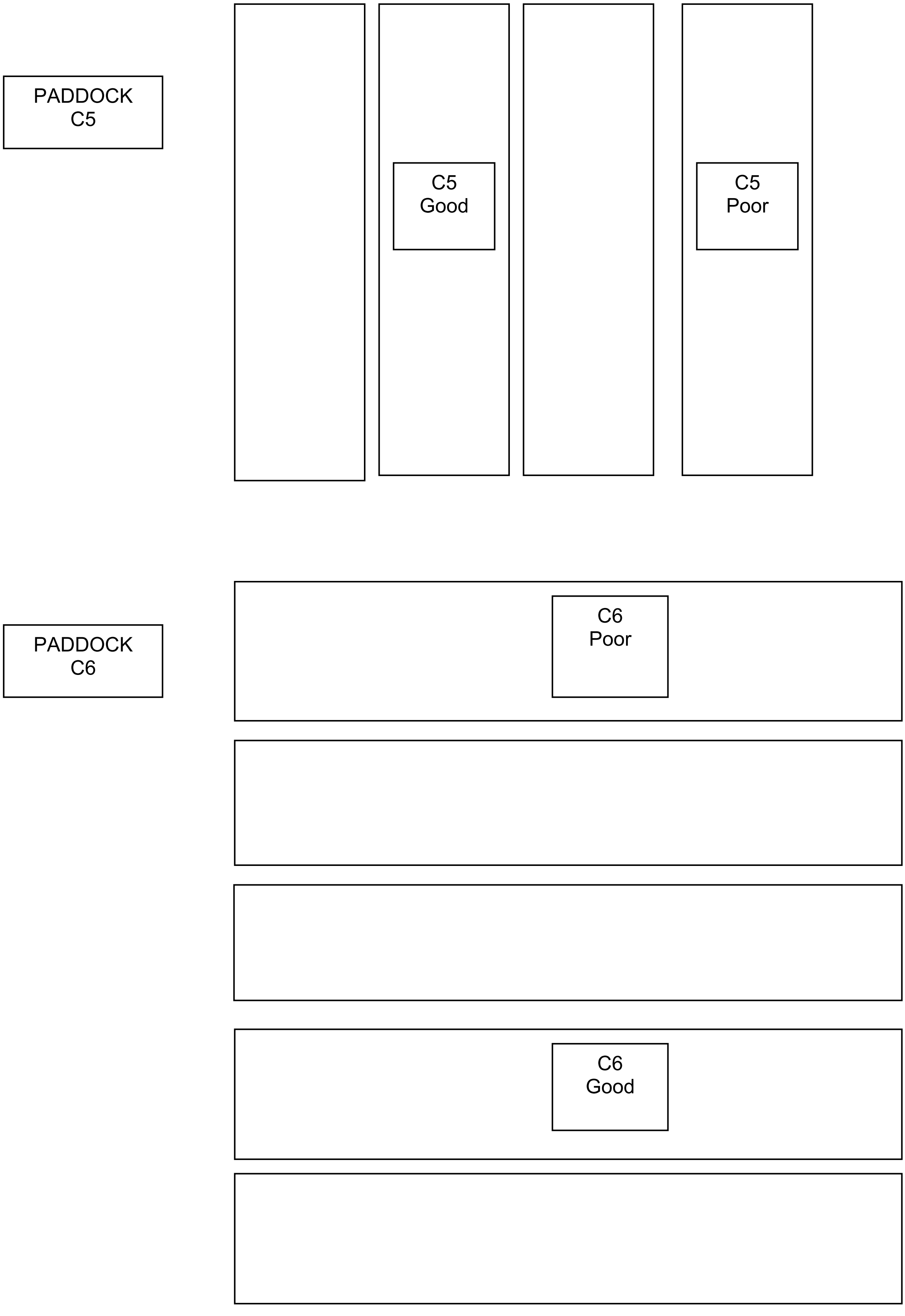
Appendix 1

The four bays sampled in paddocks C5 and C6 at the WTP.



Appendix 2

Photos of the four bays sampled at the WTP.

A

B

C

D

A) Bare dry soil with cracks in the middle of a bay.

B) Poor performing maize, 0.1-1m tall and wide apart.

C) Tall weed amongst the maize.

D) Brown and yellow leaves at the base of the crop.

Appendix 3

Paddocks C5 & C6 in the north-west corner of the WTP are marked with an arrow.